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How Could Unmanned Aerial Systems (UAS) Be Used for Ecohydrological and Ecosystem Research? Experiences of First Operations with UAS in River Flood Plains of Northern Mongolia

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How could unmanned aerial systems (UAS) be used for ecohydrological and ecosystem research? Experiences of first operations with UAS in river flood plains of Northern Mongolia

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Abstract

This paper proposes the use of unmanned aerial systems (UAS) as a method for monitoring biotic resources and ecohydrological systems in river floodplains.

Small scale mapping based on LANDSAT and SRTM or ASTER data is of limited applicability since a spatial resolution of 30 to 90 m is not sufficient to meet the demands of habitat mapping and large scale 3D -modelling. Newer satellites like WorldView2 and SENTINEL (space mission from European Space Agency within the Copernicus Programme) could be an option to gain a 0.5 m resolution, but the availability of image data is limited.

UAS allow the collection of very high spatial and temporal resolution image data and the generation of digital elevation models (DEM). A spatial resolution of less than 10 cm and multispectral or hyperspectral image data, which can be provided by UAS sensors, is needed for mapping of habitats and riparian vegetation. Indicators for water quality such as chlorophyll (a) and suspended matter concentration can be efficiently derived from multispectral image data. Thermal image data, which can also be recorded by UAS-borne sensors, provides information on thermal heterogeneity of water temperature and the interaction of river and groundwater discharge from the river floodplain. In addition, cloud cover rarely affects UAS-generated aerial images because flying altitudes are usually low and flight missions can be timed very flexibly. UAS are also much more cost-effective to operate than manned aircraft.

In a first field survey in September 2012, several field plots were investigated in northern Mongolia in different watersheds of the Selenge River Basin (SRB) with varying types of land use and environmental impacts. The regional focus was on the Kharaa River Basin (KRB), which is a paradigm for transformation from nearly natural conditions to an increasingly altered state by economic activities. Within the BMBF funded project “Integrated Water Resources Management in Central Asia: model region Mongolia (MoMo)” the actual situation of water quality, quantity and ecological impacts in this area has been investigated since 2006.

A first analysis of nutrient and ecological gradients of the Kharaa Rver Basin indicates a ‘good’ chemical and ecological status for the headwaters and some parts of the middle reaches. Evidence for initial processes of ecosystem degradation and biodiversity loss were detected in the middle and increasingly in the lower reaches. Despite many efforts, several questions remained unsolved. Among them, the impact of erosion and particle transport on ecosystem degradation is a key issue. Fine sediment intrusion caused by erosion predominantly from the river banks but also from upland areas seems to be the most likely cause. However, based on the experiences of our existing monitoring scheme with a combination of intense fieldwork and continuous measuring with data loggers, the need of more spatial information (e.g. riparian vegetation structure, hydromorphology) with a high resolution became evident to confirm this hypothesis.

Therefore, an unmanned aerial vehicle (UAV) equipped with a calibrated RGB camera was used to record image data for photogrammetric processing. DEM and orthophotos as well as spherical panoramic views were derived. Furthermore, thermal image data were terrestrially collected using an Infratec Variocam hr. Integration of thermal, multi- or hyperspectral sensors on various UAS (e.g. Archaeocopter), as well as analysis algorithms are the next steps for future work.

The applicability of remote sensing approaches is discussed to better foster the development of ground truthing for a sustainable river basin management plan. The application of UAS offers a sound scientific base to assess especially the riparian zones in areas with difficult access.

Keywords: remote sensing, UAS, habitat mapping, ecosystem service; river meadow ecology, Kharaa River; Mongolia

Introduction

In the framework of the BMBF (Federal Ministry of Education and Research of Germany) funded IWRM Project MOMO (website: http://www.iwrm-momo.de), a comprehensive monitoring project (2006–2013) provided data on hydrology (MENZEL et al. 2011), hydromorphology, climatology, water physico-chemistry, sedimentology (HARTWIG & BORCHARDT 2014, THEURING et al. 2015), macroinvertebrate community (AVLYUSH et al. 2013) and fish diversity (KRÄTZ 2009, KRÄTZ et al. 2010) in the Kharaa River Basin (KRB) in northern Mongolia. For the first time, this dataset enabled a detailed characterization and assessment of the stream landscapes within the KRB (HOFMANN et al. 2015) with data scarcity as a challenging task (KARTHE et al. 2015). Although the KRB is characterized by a relatively low population density (8 to 10 people per km²), spatial concentrations of population in urban settlements, an often poor state of municipal wastewater infrastructures, and high livestock densities in the riverine floodplains as well as both small and large-scale mining activities all contribute to the potential threats facing the aquatic ecosystems of the KRB. In our study, the identified key stressors affecting water quality and the aquatic ecosystem of the KRB were:

- (i) rising nutrient inputs;
- (ii) high fine sediment loads; and
- (iii) mining-related influxes of toxic substances (HOFMANN et al. 2015).

Intensive livestock farming in the floodplain (overgrazing), soil compaction by livestock trampling and timber logging are the main causes for river bank instability and river bank erosion (THEURING et al. 2013). Subsequently there is an obvious decrease of riparian vegetation by means of decreasing biomass and decline of wooden vegetation. Hence, a better knowledge of the interface between terrestrial and aquatic ecosystems is necessary to test general hydrogeomorphic and ecological concepts (TOCKNER et al. 2010, McLAIN et al. 2003).

According to several detailed field studies in KRB, river bank erosion generates 74.5 % of the suspended sediment load, whereas surface erosion contributes 21.7 % and gully erosion only 3.8 % (THEURING et al. 2013). The importance of river bank erosion is shown to increase from upstream to midstream tributaries (THEURING et al. 2015). Erosion due to agricultural land use is of minor importance. Fine-grained sediment emission by settlements is likely to occur (e.g., deterioration of water ecology downstream of Zuunkharaa and Baruunkharaa) (HARTWIG et al. 2012, HARTWIG & BORCHARDT 2014). The increasing input of fine-grained sediments in the flowing water causes decrease in the benthic primary production and affects the permanent function of the hyporheic zone. Moreover, impairment of the hydraulic exchange causes a loss of habitat function and deteriorates the self-purification potential concerning nutrient retention and processing.

Possible countermeasures consist in the introduction of comprehensive grazing management and the installation of protective area concepts to support the recolonization of natural river bank vegetation especially in the Kharaa middle reaches.

To provide spatial information adequate to the scale of the study, satisfactory spatial and temporal resolution, and reasonable operation costs we decided to apply the UAS technology for the first time in KRB. Based on a Memorandum of Understanding of four contracting partners (Mongolian Academy of Sciences (MAS), University Bonn (UB), Freie Universität Berlin (FUB) and Forschungsverbund Berlin (FVB) including the Leibniz Institute for Freshwater Ecology and Inland Fisheries (IGB)) this offered the opportunity to enhance existing monitoring programmes with low cost remote sensing approaches by using UAS. In the presented study, we focused on the vegetation density and morphodynamics of river floodplains with octocopter-mounted cameras. In September 2012, the Leibniz Institute for Freshwater Ecology and Inland Fisheries (IGB) and the Dresden University of Applied Sciences (HTW Dresden) conducted a first test on the benefits and advantages of small drone aerial images to support monitoring of fresh water resources, geomorphic and vegetation pattern analysis.

An Ascending Technologies Falcon 8 octocopter carried a Sony NEX 5 16 Megapixel camera. A total of two orthomosaics and ten spherical panoramas were processed. These images supported a better understanding and offered a more sophisticated way not only to find and evaluate the right position for data loggers in the water body but also to supply high-resolution maps of vegetation patterns such as evaluating land use impacts on structural diversity.

Material and Methods

UAS Technology - an overview

Among the various remote sensing platforms the physical size and power of rotor-based UAS sets some limits with regard to their payload carrying capacity, operating altitude, and range (fig. 1). Since various different UAS classification systems exist already (ANDERSON & GASTON 2013, WATTS et al. 2012), we focus in our contribution on rotor-based lightweight systems, also known as “microcopters”.

UAS equipped with full frame cameras are powerful and effective tools for the acquisition of high resolution aerial images. These images can be used to create orthophotos, orthophotomosaics, Digital Surface Models and 3D perspective views of monitoring spots in Mongolia (OCZIPKA 2009). In 2008 this technology was new and relatively expensive. Even more expensive than the UAS was the photogrammetric processing software. Image processing was done by specialists and quite complicated, because software like INPHO or LEICA Photogrammetry Suite ® was not really made for the processing of this kind of images at this time, but instead for large professional aerial photographies recorded by aerial cameras such as Vexcel`s Ultracam XP or Z/I-Imaging`s DMC.

This has changed significantly in recent years. UAS like the Phantom 2 are inexpensive and equipped with small, relatively high-quality cameras like the GoPro and they have become a widespread toy and tool.

Photogrammetric processing and computer vision algorithms have also been improved, and such processing can now be done using freeware such as vSFM, CMVS, Bundler or MicMac. Based on vSFM, other low cost software like AGIsoft`s Photoscan also support the processing of large Ultracam as well as imagery from any digital camera. While the vSFM freeware needs basic understanding about the matching algorithms, aerotrinagulation and bundle adjustment, low cost software could be easily used by amateurs with a small learning curve.

Prices for professional small drone systems and photogrammetric software have decreased over the last eight years from several 10k€ to 2k€ or less. At the same time, the photogrammetric processing became more accessible to normal users.

In our study, we used a microcopter with eight sets of rotor blades (“octocopter”, the Ascending Technologies Falcon 8 system), with the rotor blades being arranged along two arms located on either side of the payload (fig. 2). The octocopter can be controlled in a precise manner since the angular velocities of the individual rotor blades can be adjusted easily and automatically by the on-board control electronics. This system can remain airborne even if one of the rotors loses power.

For the spatial research of our field campaigns, we had to take into account the following operational considerations:

a) Platform constraints: Flight endurance was restricted not only by payload capacity but also by the electrical power supply of the rechargeable batteries to max 10 minutes. To ensure a sufficient buffer time for safe starting, and return flight procedures we decided to limit the real flight time to 7 minutes.

b) Sensor constraints: Limited payload size restricted the use to digital RGB cameras; the geometric accuracy of spatial data can only be validated in relation to accurately surveyed ground control points.

c) Operating constraints: The system requires GPS-enabled navigation, while take-off and landing procedures are typically pilot-controlled. Flight restrictions posed by civil and federal aviation have to be cleared.

d) Environmental constraints: To avoid an increased risk of complete system loss in high winds, the wind velocity at the ground should not exceed 10 m sec^{-1}. Note that in flight elevations of several decametres above ground the wind velocity may increase significantly, making the return flight to the starting point difficult. This is important for planning sufficient buffer time.

Technical details for the chosen octocopter and the RGB digital camera are given in fig. 2, 3, and table 1.

		Satellites	Airplanes	e.g. Cessna	UAVs (25 - 150 kg)	UAVs (< 5 kg)
Altitude	km	450 – 1000	0.1 – 10	0.1 – 6	0.001 – 2	0.001 – 0.5
Image area	km²	3000 / image	100 – 500 / day	< 500	10 – 50 / day	2 – 5 / day
Resolution	m	0.5 – 25000	0.07 – 200	~0.1 – 10	0.01 – 0.5	0.01 – 0.5
Flight time	h	> 5 years	up to 10	< 4.5	1.5	0.5
Payload	kg	> 1000	100 – 200	< 400	15 – 20	0.5 – 2
Operating cost	€/h	*(N/A)*	200 – 1000	800 – 1500	20 – 100	1 – 10

Fig. 1: Comparison of remote sensing platforms.

- Weight: 2 kg incl. 600 g payload
- Engine: 8 rotors, electric, Li-Ion battery
- Flight Time: 10-20 min. (depending on payload, wind)
- Speed: max. 29 km/h
- Payloads:
  - Digital Camera
  - Infrared Camera
  - non-imaging spectrometer (possible development)
- Fully GPS-assisted flight
- Waypoint missions
- Single 85 x 72 x 46 cm transport case

Fig. 2: Technical details of Remote sensing platform Asc Tec Falcon 8.

The measurement equipment plan of the chosen Falcon 8 octocopter included a digital RGB camera and a thermal IR Infratec Variocam hr camera (spectral range 7.5-14 µm, temperature sensitivity < 0.08 K, resolution 640 x 480 pixel). However, due to the limited payload only a terrestrial application of the thermal IR camera was possible. With new developments, the size of infrared cameras has been reduced to enable them to be carried within the payload of the Falcon 8. However, the image quality of the currently available small infrared cameras does not yet exceed that of the larger cameras.

Table 1: Technical Data for the octopter and the mounted RGB camera in a flight altitude of 91 m above ground for a specific flight mission in the middle reaches of Kharaa River

technical data of Falcon 8 octocopter	**data**		**unit**	
company	Ascending Technologies GmbH			
year of construction	2012			
max. flight time	25		min.	
max. flight altitude	300		m	
max. payload	250		gram	
parameter Camera Sony NEX5N	**in flight attitude**		**transverse to flight attitude**	
camera parameter		**unit**		**unit**
focal length	16	mm	16	mm
pixel distance	4,76	µm	4,76	µm
pixel counts	4912		3264	
max. angular aperture transverse to flight attitude	72,3	°	51,8	°
flight mission parameters				
mean relief elevation	1250	m	1250	m
maximum relief elevation	1300	m	1300	m
flight elevation above seal level	4.400	ft	4.400	ft
flight elevation above ground	91	m	91	m
overlapping	85	%	85	%
spatial resolution	2,7	cm	2,7	cm
size of recorded ground surface per picture	133	m	88	m
distance of scene centre points	20	m	13	m
overlapping at maximal flight elevation	67	%	67	%

Study sites during field campaign in 2012

Our study sites P1 to P7 were located within different vegetation zones starting from the source region of Kharaa River (coniferous forest and mountain steppe with transition to Siberian taiga in the West Khentii), following the middle and lower reaches of Kharaa (temperate grasslands and shrublands) until the open grasslands within the eastern foothills of Selenge-Orkhon River Basin (fig. 4). Detailed descriptions of the study sites are given in HOFMANN et al. (2015). The focus concentrated on the river meadow plains with special attention to the riparian zones. We selected seven study areas covering up to 0.49 km^2 to take high-resolution RGB images at flying altitudes of 100 to 150 m above ground (table 2).

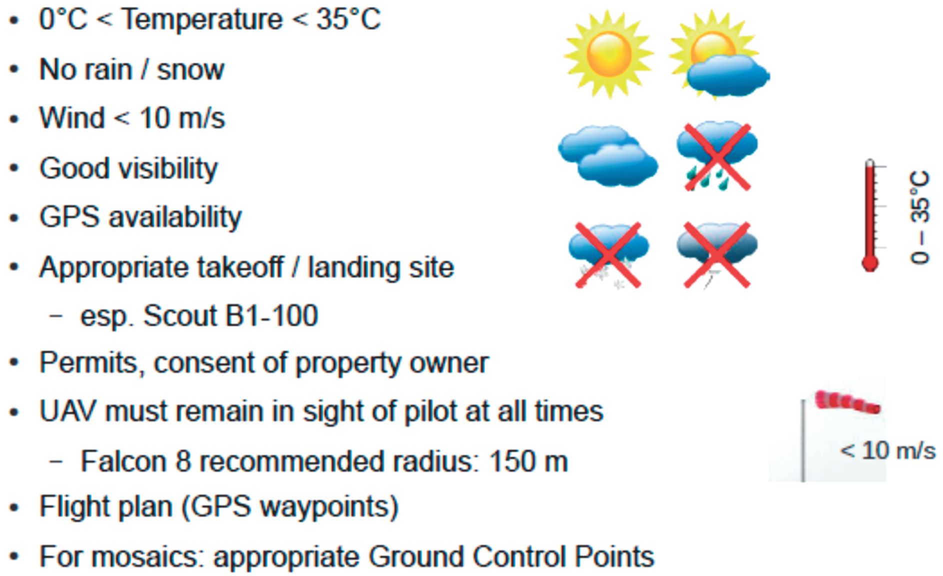


Fig. 3: Typical preconditions for measurements with UAS including Asc Tec Falcon 8.

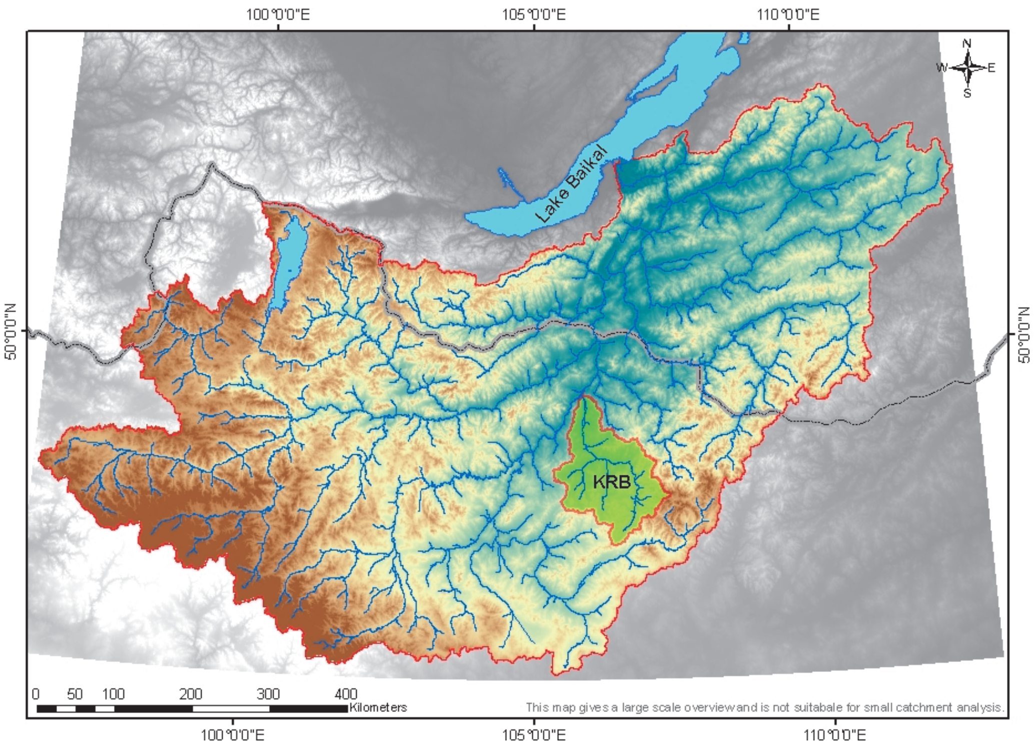


Fig. 4: Orohydrographical map of the Selenge River Basin (SRB, catchment area 459,000 km^2) in northern Mongolia with the location of the Kharaa River Basin (KRB, catchment area 14,534 km^2) and study areas P1 to P7 (see Table 2, HOFMANN et al. 2015).

Table 2: List of selected study areas P1 to P7 with spherical panorama (P) views

No.	location and short description of study area	geogr. coordinates and elevation	UAS Imagery Date (DDMMYY) time	references
P1	Khonin Nuga valley, West Khentii Mts., German/ Mongolian ecological research station with focus on long-term biodiversity research	49°05'4.60"N 107°16'55.30"E 940 m a.s.l.	OCZIPKA (2015a) 15.09.2012 13:00 local time	MÜHLENBERG 2012
P2	Churcheree Gol, West Khentii Mts., study site of Heidelberg University on evapotranspiration, energy balance, soil moisture dynamics and water chemistry; effects of wildfire	48°26'50.04"N 107°12'29.1"E 1506 m a.s.l.	OCZIPKA (2015b) 07.09.2012 10:00 local time	HOFMANN et al. 2015 MINDERLEIN et al. (2014) KOPP et al. (2014)
P3	Churcheree Gol, West Khentii Mts., study site of terrestrial thermal IR imagery	48°26'50.6"N 107°11'23.9"E 1546 m a.s.l.	OCZIPKA (2015c) 06.09.2012 20:30 local time	HOFMANN et al. 2015 MENZEL et al. 2011
P4	middle reaches of Kharaa River, study site of water quality, discharge and biodiversity near Unigt	48°49'46.81"N 106°39'28.03"E 905 m a.s.l.	OCZIPKA (2015d) 12.09.2012 17:00 local time	HOFMANN et al. 2011 HOFMANN et al. 2015 BERNER 2007 AVLYUSH et al. 2013
P5	middle reaches of Kharaa River, study site of water quality, discharge and biodiversity at Baruunkharaa	48°54'41.94"N 106° 4'30.12"E 798 m a.s.l.	OCZIPKA (2015a) 14.09.2012 17:00 local time	HOFMANN et al. 2010, 2011, 2015 MENZEL et al. 2011
P6	confluence of the Kharaa River and the Orkhon River, study site on long-term discharge and water quality	49°37'53.83"N 105°50'0.86"E 664 m	OCZIPKA (2015e) 11.09.2012 10:30 local time	HOFMANN et al. 2013, 2015
P7	Selenge valley, 7 km northwest of Zuunburen village, floodplain meadow with remnants of riverine forests and intense land use close to the riparian areas (rotation sprinkler irrigated wheat fields and livestock husbandry)	50° 6'15.14"N 105°48'9.30"E 634 m	OCZIPKA (2015f) 11.09.2012 12:50 local time	HOFMANN et al. 2015

Workflow of aerial imaging process

Each imaging campaign of UAS application has to be correctly prepared before the flight. The aerial planning starts with analytical considerations setting the parameters for imaging such as instrument calibration, flying height, focal length of the camera, image scale, distance between two points where the image is taken and GSD (Ground Sample Distance).

To give an example, about 100 waypoints (marked in yellow) of each photo are needed to assure sufficient overlapping and to cover an area of approx. 700 x 700 m (0.49 km^2) within a flight time of maximal 10 minutes (fig. 5). Exemplary situations are shown in fig. 6 to 8.

The subsequent operational phase includes setting up the flight route plan and is used to design the flight route in the form of flight lines and waypoints. The UAS then flies along these lines and captures the images. Although we could take only “snapshots” during our fieldwork, the flight routes can be of benefit to repeated imaging campaigns in future to ensure comparable conditions for the acquisition of imagery. In the field the flight planning can be adjusted to the real conditions.

During take off and landing the pilot has to control the UAS motion directly. After having reached the planned flight level the UAS moves automatically along the flight lines. In emergency situations the mission can be stopped by using the “abort mission” function and the UAS returns to the starting point.

The post-processing of the generated data is the most time consuming part. This phase includes the image processing, mosaicing and the accuracy assessment. The stitching of overlapping photos allows the generation of spherical panoramas. An important step is the reconstruction for image orientation and calculation of the exterior orientation parameters based on the technology “Structure from Motion” (SfM) to restitute the three-dimensional geometry of an object or surface by using images acquired from multiple viewpoints (FONSTAD et al. 2013). In the post-processing phase of data evaluation and interpretation, capacity development of young researchers (e.g. master thesis etc.) can be performed with mutual benefit for both, students (KÖSER-UNRUH 2014, PREUSS 2014) and scientists (OCZIPKA 2015 a-f).

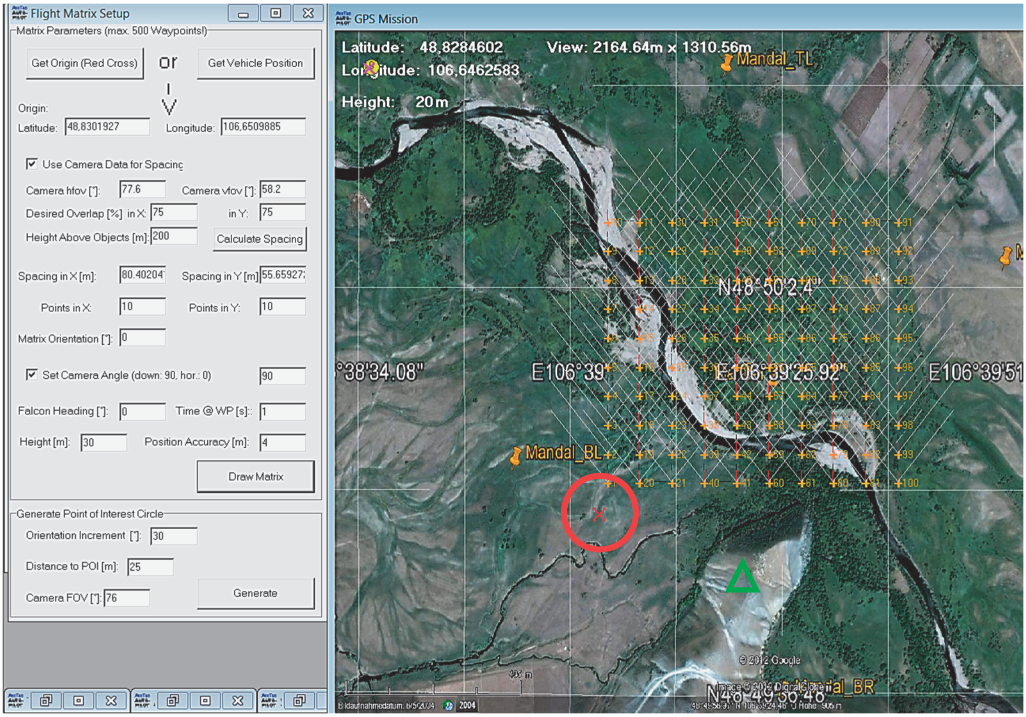


Fig. 5: Graphical interface of the flight planning software with flight lines and waypoints (yellow) covering an area of ca. 0.49 km^2 at study area P4. The actual position of the octocopter is shown with a red cross (marked with a red circle). The starting point is marked with a green triangle (GPS coordinates: 48°49'44.51"N; 106°39'22.71"E; 928 m above mean sea level). Screenshot from Falcon flight planning tool.

How to create and view spherical panoramas?

Spherical panoramas have been created by stitching overlapping photos with the software PTGui Pro (OCZIPKA 2015). The result is a panorama where the user can see the full environment of the octocopter-mounted camera. The desired panorama can be activated by clicking the given website links (OCZIPKA 2015a to e) and then the picture on the computer monitor is shown. The integrated Flash Viewer enables the user to move the panorama in any desired direction with the mouse. A full screen view and zoom in function is also available by clicking the symbol (square with four arrows) in the upper right corner of the panorama view. You can leave the full screen view by pressing the “Escape” key on the PC keyboard. Due to payload restrictions the spherical thermal IR panorama view (Picture 10 B) was terrestrially collected using an Infratec Variocam hr camera (spectral range 7.5-14 µm, temperature sensitivity < 0.08 K, OCZIPKA, M. 2015c). All other spherical panoramas were airborne collected.

Fig. 6: Pilot (M. Oczipka, right) and flight assistant (J. Hofmann, left) during flight operation on 08.09.2012 at study area P4 (see Fig. 4, Table 2) near Unigt.

Fig. 7: Octocopter FALCON 8 with camera SONY NEX5N during flight operation 10.09.2012.

Fig. 8: Take off area of Octocopter FALCON 8 from top of the transport case 12.09.2012.

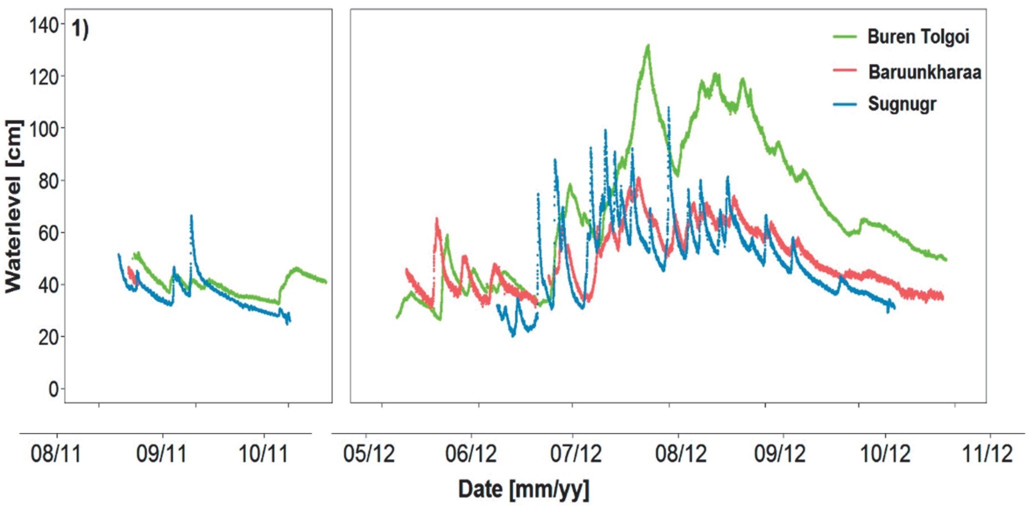


Fig. 9: Variations of water levels during the summer periods in 2011 (Aug-Oct) and 2012 (May-Nov.) at the automatic water quality monitoring stations Buren Tolgoi (near confluence of Kharaa River and Orkhon River; study area P6, 664 m a.s.l.), Baruunkharaa (middle reaches; study area P5, 796 m a.s.l.) and Sugnugr (Upper reaches in Khentii Mts. study area P2 and P3, 1180 m a.s.l. HOFMANN et al. 2015). The UAS flight missions were performed from the 6th to 15th September 2012 during the period of decreasing discharge.

Results and discussion

Our field investigations in early September 2012 took place during a period of decreasing discharge after several summer rainfall events. This is indicated by the water levels of three different monitoring stations positioned in the upper (Sugnugr, Khentii Mts.), middle (Baruunkharaa) and lower reaches (Buren Tolgoi, river basin outlet) in Figure 9.

Among the various study sites two selected examples are shown for documentation of the results. The study site P1 (Khonin Nuga) has been investigated in detail by the efforts of a longterm biodiversity research progamme in cooperation between Göttingen University and National University of Mongolia since 1997 (MÜHLENBERG 2012) so that we restricted our field work to provide the spherical panorama of the Khonin Nuga valley as a tool for visualization.

Mountainous headwater areas at Sugnugr Gol/Khentii Mts. (Study area P2 and P3, (Churcheree Gol)

The upper reaches of KRB are characterized by mid to high mountain ranges of the Khentii Mountains belonging to the semi-arid forest-steppe ecotone. Since these headwaters generate the highest specific runoff rates, they are the main water source or "water tower" for the lower catchment. The tributary Sugnugr Gol and its side branch Churcheree Gol in the upper site of the headwaters, is virtually unaffected by direct human impacts due to its remote location and can be used as natural background condition also in terms of water quality parameters (HOFMANN et al. 2015).

However, effects of a recent forest fire (2007) have affected this fragile ecosystem and especially favoured the degradation of the existing discontinuous permafrost. Hence, the forest cover and the distribution of the coupled permafrost-forest system are decreasing. Once permafrost is degraded, water stress generally increases on the long-term, resulting in an expansion of steppe areas. This has been investigated in detail by a research team of Prof. Dr. Lucas MENZEL from Heidelberg University. The semi-arid forest-steppe ecotone in the Khentii Mountains in Northern Mongolia is characterized by southerly exposed steppe slopes, shrublands in the floodplain of river valleys and northerly exposed taiga slopes (MINDERLEIN & MENZEL 2014). Although forest fires can frequently occur during dry periods in Mongolian boreal forests (HESSL et al. 2012), satellite imagery collected since the 1960s shows that the study site was unaffected by forest fires during this period or longer (e.g., Corona and LANDSAT, KOPP et al. 2014). This offered the opportunity to provide high resolution spatial information of the lightly burned, heavily burned areas and the pristine forest at study site P2 and P3. The effects of fire on soil moisture dynamics and ecosystem functioning were investigated by KOPP et al (2014). Until today, the heavily burned area is very sparsely covered with vegetation as succession hardly proceeded.

The imagery taken on study site P2 covers the range of deciduous shrubbery, consisting mainly of *Betula fusca* and *Dasiphora fruticosa*, occasionally accompanied by *Salix rhamnifolia* and *Salix pseudopentandra*. The northerly exposed slopes exhibit cool and moist soil conditions and are covered by dense taiga consisting mainly of *Pinus sibirica*, *Larix sibirica*, and *Betula platyphylla* and a thick organic layer of mosses and small shrubs, predominantly *Ledum palustre* and *Vaccinium vitis-idaea* (KOPP et al. 2014).

A spherical thermal IR panorama view of fig. 10 (B) was terrestrially collected using an Infratec Variocam hr camera (spectral range 7.5–14 µm, temperature sensitivity < 0.08 K) on 6 September 2012, 8:30 p.m. local time, two hours after sunset. The thermal heterogeneity measured two hours after sunset shows a clear reversed altitudinal zonation of temperature regime with relatively cold valley bottom (-0.2 °C) to west exposed slopes with surface temperatures of up to 12 °C. Isolated spots of much higher surface temperature (up to 16.4 °C) are marked in areas with moss covered blocks. These block fields can store thermal energy over longer time. Such findings offer new perspectives also for habitat and biodiversity research as TONOLLA et al. (2010) have elaborated it.

River meadow plains and status of riparian vegetation in Kharaa, Orkhon and Selenge Rivers (Study areas P3 to P7)

The status of river meadow plains and especially of riparian vegetation has been investigated along a section from the headwaters of Kharaa until downstream of the confluence with Orkhon River and the Selenge River. Along the Kharaa main river course only patches of riverine forests in floodplain areas still exist near Unigt (fig. 10 B, study area P4) and in the confluence area with Orkhon River (fig. 10 D, study area P6). The extreme degradation of vegetation cover and the soil compaction by intense land use intensity of livestock husbandry favours erosion especially at river banks in the middle (fig. 10 A) and lower reaches (fig. 10 C) of Kharaa River.

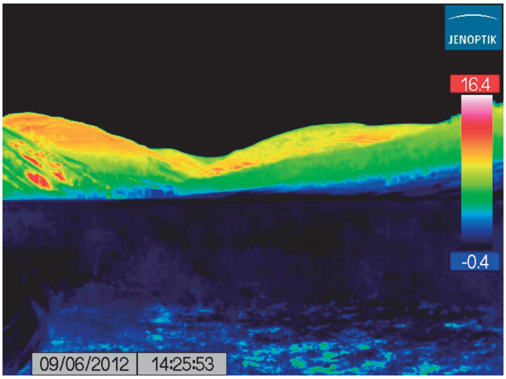
Further downstream at the Selenge River the situation in the river floodplains is characterized by higher vegetation cover and the existence of a mosaic from riverine forests and floodplain meadows**.**

Submerged aquatic and floating-leaved plants are typical of this peripheral area of Selenge river, while emergent wetland plants and facultative-upland species grow in marshes, wet meadows, and areas of slightly higher elevations. Scrub-shrub plants (e.g., *Salix* spp.) are typically distributed along the natural levees of current and abandoned stream channels. However the increasing loads of fine-grained sediments are detectable being a major stress factor causing adverse impacts on the benthic ecology as it has already been stated by HARTWIG (2012) and HARTWIG & BORCHARDT (2014) in KRB. However, the current knowledge about the spatial distribution and abundance of wetland habitats in the Selenge River flood plain, which hampers efforts to not only characterize changes to this wetland of international importance, but also limits the ability of resource managers to assess impacts to downstream areas (especially on Lake Baikal ecosystem). Wetland mapping and inventory represents the first step towards bridging this information gap. Wetland mapping through the use of remote sensing data will be increasingly used at both fine (UAS imagery) and regional scales (satellite imagery, LANE et al. 2015).

Conclusion and Prospects

The experience and knowledge gained in the MoMo III project will be transferred to local scientists. Several workshops in Mongolia and Germany as well as a conference are planned. The data from the two previous projects MoMo I and MoMo II will be integrated into a web mapping service. One major issue is the application of low cost hardware (e.g. multicopters), low cost software or freeware and free satellite images (e.g. LANDSAT). There are many options, e.g. Mapbender/ Mapguide or OpenGeoSuite (OGS) are freeware. OGS is a Java based freeware package, which integrates all the needed software in one “dashboard”. The package GeoServer offers the following services: CSW, WCS, WFS, WorldMAppingsService (WMS), WPS, TMS, WMS-C, WMTS, (WMS) and WPS. The software BoundlessSDK, GeoExplorer, PostGIS, OpenLayers2 and 3 and GeoWebCache are open source and freeware and are fully integrated to the dashboard. OGS is easy to learn, easy to maintain and could be adapted to the needs of scientists using JavaScript. The web mapping service will provide the satellite data, the classified image data, orthomosaics, panoramas and data from the loggers to the scientists. Classified information will be password protected. One major goal is teaching the local scientists in remote sensing, GIS, sample collection and other technologies and help them in monitoring freshwater resources in Central Asia and to maintain the freshwater management web mapping. The server will be located at the University of Applied Sciences Dresden as part of the server of the faculty Spatial Information. It can be accessed and maintained from any computer with an Internet connection.

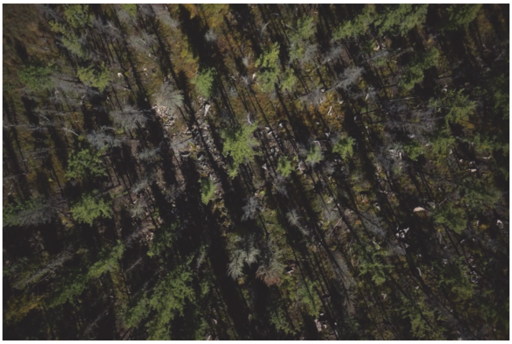
A Churcheree Gol, terrestrial view to the summit region (Study area P2, 05.09.2012; 11:45 a.m.).



B Churcheree Gol, terrestrial view as in fig. 10A to the summit region as IR image during night (06.09.2012; 8:25 p.m.).

C Octocopter image of Churcheree Gol, view east to the summit region (07.09.2012; 10:00 a.m.).

D Vertical view to Curcheree Gol (06.09.2012; 11:30 a.m.).



E Partially burnt forest with isolated green trees in Churcheree Gol (study area P2).

F Deciduous shrubland with isolated burnt trees (vertical view 06.09.2012; 11:20 a.m.).

Fig. 10: Study area P2 in Churcheree valley, a tributary in the Sugnugr basin in the West Khentii Mts. documenting the general situation (A) the thermal heterogeneity of the same location during night (B), part of a spherical panorama (C), vertical view to the river bed (D), impacted burnt forest (E) and regenerated deciduous shrubalnd (F). The full terrestrial IR panorama view is visible on the following website:

https://www.htwdresden.de/fileadmin/userfiles/geo/Labore/Labor_Photogrammetrie_Fernerkundung/Panorama/BaerentalThermal/06092012_Barerental_Thermal.htm.

A Kharaa River at Baruunkharaa with degraded vegetation and bank erosion, study area P5.

B Kharaa River near Unigt with remnants of riverine forests, study area P4.

C Kharaa River at Deed Guur bridge near Darkhan, view downstream.

D Confluence of sediment loaden Kharaa (right) and Orkhon River (left), study area P6.

E Selenge River (Сэлэнгэ мөрөн) with flow diversion, submerged vegetation and river banks at study area P7, view upstream.

F Selenge River (Сэлэнгэ мөрөн), study area P7, view downstream.

Fig. 11: Examples of riparian vegetation in river flood plains and river bank situations of Kharaa River, Orkhon River and Selenge River as vertical and inclined aerial images from the octopter-mounted RGB digital camera. Exact locations and date of imagery are given in table 2.

Outlook

During the ongoing MoMo-III project phase (2015 to 2018) the sub-project “Environmental monitoring” will focus on three topics in close cooperation with Mongolian partners:

First,
the setup of a sustainable environmental monitoring system based on remote sensing data combined with GIS technology for spatial investigations is an overall aim. Environmental monitoring of river meadow plains in KRB and adjacent areas will be performed with innovative remote sensing methods. The remote sensing based analysis of satellite data will be assessed by ground truthing with a combination of fieldwork and application of UAS to obtain high-resolution imagery in a short and flexible time. The establishment of a joint Mongolian-German database will provide all publicly available remote sensing data starting from the earliest available LANDSAT data since 1973 until recent satellite, aircraft and UAS. In combination with UAS-supported ground truthing the data can be applied to a wide range of purposes. This includes the change detection of hydromorphological changes and vegetation density changes of individual plots, including multitemporal analysis of stream channel changes. Further possible applications consist in the quantification of spatial gap patterns in forests (GETZIN et al. 2014), multitemporal monitoring of stream channel changes (MIŘIJOVSKÝ & LANGHAMMER 2015, WHITED et al. 2012) especially after flood events (TOCKNER et al. 2000, 2010). It also allows the survey of protective area concepts to support the recolonization of natural river bank vegetation of the Kharaa middle reaches. In addition, it provides data to foster the database of profiles of Mongolian stream types based on the methodology of BRIEM (2003) and POTTGIESSER & SOMMERHÄUSER (2004, 2008). The initial characterization of stream landscapes in KRB has been published by HOFMANN et al. (2015) and will be enlarged to adjacent river basins.

Second,
the use of software applications for evaluation of remote sensing data and its quality assurance is an important topic of capacity development for spatial ecology. Special courses will be offered for qualified users. Details of the ongoing work progress are published on the official project website (http://www.iwrm-momo.de). To facilitate a low-cost alternative we plan to construct the UAS together with Mongolian partners following the approach of the recently developed “Archaeocopter” project (Archaeocopter project 2015). The generated maps will be incorporated into a Kharaa River Basin Atlas and provided as printed and digital online versions. This atlas shall ensure the transfer and visualization of environmental monitoring results into the ongoing process of river basin management plans. Joint scientific papers of the German-Mongolian team will primarily be published in open access journals to enable a fast and license free communication process.

Third,
at the end of the MoMo-III project the following scientific products will be delivered: the joint remote sensing database, a software tool for interpretation of remote sensing imagery and a Kharaa River Basin Atlas with a set of basic information and multitemporal maps to document environmental changes. After 2018 the Mongolian side will take over the follow up process in its own responsibility.

The described outlook offers the possibility to join forces for mutual benefit and to improve the communication in the scientific community. The centralization and utilization of the scattered literature on biodiversity research methods, approaches and results is an urgent topic not only in Mongolia, but also in Central Asia. On the Int. Symposium “Biodiversity Research in Mongolia” in Halle (25-29 March, 2012) the need to set up a Data Information System (DIS) as a central database for freshwater biodiversity has been identified as a top priority issue. A first step could focus on the description of metadata describing series of measurements. Metadata represent information features for fixing the properties of these series (“Who measured what, where, when and whereby?”). Meta-information is necessary to identify and retrieve series and measurements. Based on the initial question we have to find solutions for the organization of this task within the framework of the next conference.

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References

ANDERSON, K; GASTON, K.J. (2013): Lightweight unmanned aerial vehicles will revolutionize spatial ecology. - Front. Ecol. Environ **11** (3): 138-146.

Archaeocopter project 2015: Project Archaeocopter: the flying archaeologist. - Accessed 08 July 2015. - http://www.archaeocopter.de

AVLYUSH, S.; SCHÄFFER, M.; BORCHARDT, D. (2013) Life cycles and habitat selection of two sympatric mayflies under extreme continental climate (River Kharaa, Mongolia). - Int. Review of Hydrobiology **98**: 141–154. - DOI 10.1002/iroh.201301628.

BERNER, S. (2007) Hydromorphologische Untersuchungen an einem Fließgewässer im Norden der Mongolei (Kharaa Einzugsgebiet): Grundlagenerarbeitung für die Interpretation biologischer Daten, Diplomarbeit, Universität Kassel.

BRIEM, E. (2003) Gewässerlandschaften der Bundesrepublik Deutschland. - ATV-DVWK Arbeitsbericht GB1, Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall, 1-176. Hennef, Germany.

FONSTAD, M.A.; DIETRICH, J.T.; COURVILLE, B.C.; JENSEN, J.L.; CARBONNEAU, P.E. (2013): Topographic structure from motion: A new development in photogrammetric measurement. - Earth Surf. Process. Landf. **38**: 421–430.

GETZIN, S.; NUSKE, R.; WIEGAND, K. (2014): Using Unmanned Aerial Vehicles (UAV) to Quantify Spatial Gap Patterns in Forests. - Remote Sens. **6**: 6988-7004. - doi:10.3390/rs6086988.

HARTWIG, M.; THEURING, P.; RODE, M.; BORCHARDT, D. (2012) Suspended sediments in the Kharaa River catchment (Mongolia) and its impact on hyporheic zone functions. - Environ. Earth Sci. **65**:1535–1546. - DOI 10.1007/s12665-011-1198-2.

HARTWIG M.; BORCHADT, D. (2014) Alteration of key hyporheic functions through biological and physical clogging along a nutrient and fine-sediment gradient. - Ecohydrology, Published online in Wiley Online Library (wileyonlinelibrary.com). - DOI: 10.1002/eco.1571.

HESSL, A.E.; ARIYA, U.; BROWN, P.; BYAMBASUREN, O.; GREEN, T.; JACOBY, G.; KENNEDY SUTHERLAND, E.; NACHIN, B.; STOCKTON MAXWELL, R.; PEDERSON, N.; DE GRANDPRÉ, L.; SALADYGA, T.; TARDIF, J.C. (2012): Reconstructing fire history in central Mongolia from tree-rings. - Int. J. Wildland Fire **21**(1): 86–92. - doi: http://dx.doi.org/10.1071/WF10108.

HOFMANN, J.; VENOHR, M.; BEHRENDT, H.; OPITZ, D. (2010): Integrated Water Resources Management in Central Asia: Nutrient and heavy metal emissions and their relevance for the Kharaa River Basin, Mongolia. - Water Science and Technology **62**.2: 353-363.

HOFMANN, J.; HÜRDLER, J.; IBISCH, R.; SCHAEFFER, M.; BORCHARDT, D. (2011): Analysis of Recent Nutrient Emission Pathways, Resulting Surface Water Quality and Ecological Impacts under Extreme Continental Climate: The Kharaa River Basin (Mongolia). - Int. Rev. Hydrobiology **96** (5): 484-519.

HOFMANN, J.; RODE, M.; THEURING, P. (2013): Recent developments in river water quality in a typical Mongolian river basin, the Kharaa case study. - IAHS Red Book Series (Understanding Freshwater Quality Problems in a Changing World: Proc. IAHS-IAPSO-IASPEI Assembly, Gothenburg, Sweden, July 2013. - IAHS Publ. 2013, **361**: 123-131.

HOFMANN, J.; KARTHE, D.; IBISCH, R.; SCHAEFFER, M.; AVLYUSH, S.; HELDT, S.; KAUS, A. (2015): Initial Characterization and Water Quality Assessment of Stream Landscapes in Northern Mongolia. - Water 2015, **7**: 3166-3205. - doi:10.3390/w7073166.

KARTHE, D.; HOFMANN, J.; IBISCH, R.; HELDT, S.; WESTPHAL, K.; MENZEL, L.; AVLYUSH, S.; MALSY, M. (2015) Science-Based IWRM Implementation in a Data-Scarce Central Asian

Region: Experiences from a Research and Development Project in the Kharaa River Basin, Mongolia. - Water, Special Issue “Sustainable Water Management and Decision Making under limited Data Availability”. - Water **7**: 3486-3514. - doi:10.3390/w7073486.
KÖSER-UNRUH, O. (2014): Fernerkundliches Monitoring von Flussauen in der Mongolei auf Basis von LANDSAT-, ASTER- und RapidEye-Daten. - Diplomarbeit Hochschule für Technik und Wirtschaft Dresden, Fakultät Geoinformation, 69 S.
KOPP, B.; MINDERLEIN, S.; MENZEL, L. (2014): Soil moisture dynamics in a mountainous headwater area in the discontinuous Permafrost Zone of Northern Mongolia. - Arct. Antarct. Alp. Res. **46:** 459-470.
KRÄTZ, D. (2009): Ökologie der Fischbestände in Fließgewässern des Khentii-Gebirges (Mongolei) Bestandsaufbau, Dynamik und Gefährdung durch den Gold-Tagebau. - Ph.D. thesis, Technical University of Dresden; 174 p. - http://www.qucosa.de/fileadmin/data/qucosa/documents/557/1244819085170-0070.pdf.
KRÄTZ, D.; IBISCH, R.; AVLYUSH, S.; GANGANMURUN, E.; SONINKHISHIG, N.; BORCHARDT, D. (2010): Impacts of open placer gold mining on aquatic communities in rivers of the Khentii Mountains, North- East Mongolia. - Mongol J Biol Sci **1**: 41–50.
LANE, C.R.; ANENKHONOV, O.; LIU, H.; AUTREY, B.C.; CHEPINOGA, V. (2015): Classification and inventory of freshwater wetlands and aquatic habitats in the Selenga River Delta of Lake Baikal, Russia, using high-resolution satellite imagery. - Wetlands Ecol. Manage. **23**:195–214. - DOI 10.1007/s11273-014-9369-z.
McCLAIN ME, BOYER EW, DENT CL, GERGEL SE, GRIMM NB, GROFFMAN PM, HART SC, HARVEY JW, JOHNSTON CA, MAYORGA E, MCDOWELL WH, PINAY G. (2003): Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems. - Ecosystems **6**: 301–12.
MENZEL, L.; HOFMANN, J.; IBISCH, R. (2011): Untersuchung von Wasser- und Stoffflüssen als Grundlage für ein Integriertes Wasserressourcen-Management im Kharaa-Einzugsgebiet, Mongolei. - Hydrologie und Wasserbewirtschaftung **55** (2): 88-103.
MINDERLEIN, S.; MENZEL, L. (2014): Evapotranspiration and energy balance dynamics of a semi-arid mountainous steppe and shrubland site in Northern Mongolia. - Environ. Earth Sci. **73**: 593–609. - doi:10.1007/s12665-014-3335-1.
MIŘIJOVSKÝ, J.; LANGHAMMER, J. (2015): Multitemporal Monitoring of the Morphodynamics of a Mid-Mountain Stream Using UAS Photogrammetry. - Remote Sens. **7**: 8586-8609. - doi:10.3390/rs70708586.
MÜHLENBERG, M. (2012): Long-term research on biodiversity in West Khentey, northern Mongolia. - Erforsch. Biol. Ress. Mongolei (Halle/Saale) **12**: 27-37.
OCZIPKA, M.; BEMMANN, J.; PIEZONKA, H.; MUNKABAYAR, J.; AHRENS, B.; ACHTELIK, M.; LEHMANN, F. (2009): Small drones for geo-archaeology in the steppes: locating and documenting the archaeological heritage of the Orkhon Valley in Mongolia. In: MICHEl, U.; CIVICO, D.L. (Hrsg.): Proc. SPIE, Remote Sensing for Environmental Monitoring, GIS Applications, and Geology IX, Band 7478, Washington, S. 747806-1 - 747806-11.
OCZIPKA, M. (2015a) Monitoring from Air. Spherical Panorama view Khonin Nuga. - Available online: https://www.htw-dresden.de/fileadmin/userfiles/geo/Labore/Labor_Photogrammetrie_Fernerkundung/Panorama/CampHunnichen/DSC00074_Panorama.htm (accessed: 22. June 2015).
OCZIPKA, M. (2015b) Monitoring from Air. Panorama Churcheree Gol. - Available online: https://www.htw-dresden.de/fileadmin/userfiles/geo/Labore/Labor_Photogrammetrie_Fernerkundung/Panorama/BaerentalSuedhang/Baerental_Suedhang_DSC00066_Panorama.htm (accessed on 22 June 2015).
OCZIPKA, M. (2015c) Monitoring from Air. Terrestrial spherical thermal IR panorama view of Churcheree Gol. - Available online: https://www.htw-resden.de/fileadmin/userfiles/geo/Labore/Labor_ Photogrametrie_Fernerkundung/Panorama/BaerentalThermal/ 06092012_Barerental_Thermal.htm (accessed on 22 June 2015).
OCZIPKA, M. (2015d) Monitoring from Air. Panorama of Kharaa River floodplain at Baruunkharaa. - Available online: https://www.htw-dresden.de/fileadmin/userfiles/geo/Labore/Labor_Photogrammetrie _Fernerkundung/Panorama/KharaaBaroun/Pano_1_ KharaaBaroun_ Hoehe1.htm (accessed on 22 June 2015).

OCZIPKA, M. (2015e) Monitoring from Air. Panorama of confluence from Kharaa River and Orkhon River. - Available online: https://www.htw-dresden.de/fileadmin/userfiles/geo/Labore /Labor_Photogrammetrie_Fernerkundung/Panorama/KharaaOrkhonJunction/DSC00074_Panorama_post.htm (accessed on 22 June 2015).
OCZIPKA, M. (2015f) Monitoring from Air. Panorama of Selenge River. - Available online: http://www.htw-dresden.de/fakultaet-geoinformation/labore/photogrammetrie-fernerkundung/projekte/mongolei.html.
POTTGIESSER, T; SOMMERHÄUSER, M. (2004): Die Fließgewässertypologie Deutschlands: System der Gewässertypen und Steckbriefe zu den Referenzbedingungen. - In: STEINBERG, C.; CALMANO, W.; WILKEN, R.-D.; KLAPPER, H. (eds.): Handbuch Angewandte Limnologie. 2004, 19. Erg.Lfg. 7/04. VIII-2.1:1-16 + Anhang. ecomed Verlagsgesellschafft, Landsberg.
POTTGIESSER, T; SOMMERHÄUSER, M. (2008): Beschreibung und Bewertung der deutschen Fließgewässertypen - Steckbriefe und Anhang. 2008. available from http://www.wasserblick.net/servlet/is/ 18727/?highlight=flie%DFgew%E4ssertypen.
PREUSS, K. (2014): Erstellung von Panoramen, Mosaiken und deren Georeferenzierung aus Luftbildern einer Kleindrohne. - Bachelor Thesis, Univ. Appl. Sci. (HTW), Fac. Spatial Information, Dresden.
THEURING, P.; RODE, M.; BEHRENS, S.; KIRCHNER, G.; JHA, A. (2013): Identification of fluvial sediment sources in the Kharaa River catchment, Northern Mongolia. - Hydrol. Process. **27**: 845–856.
THEURING, P.; COLLINS, A.L.; RODE, M. (2015): Source identification of fine-grained suspended sediment in the Kharaa River basin, northern Mongolia. - Sci. Total Environ. **526**: 77–87.
TOCKNER, K.; MALARD, F.; WARD, J.V. (2000): An extension of the flood pulse concept. -Hydrol. Process **14**: 2861-83.
TOCKNER, K.; LORANG, M.S.; STANFORD, J.A. (2010): River flood plains are model ecosystems to test general hydrogeomorphic and ecological concepts. - River Res. Appl. **26**:76–86.
TONOLLA, D.; ACUNA, V.; UEHLINGER, U.; FRANK, T.; TOCKNER; K. (2010): Thermal heterogeneity in river floodplains. - Ecosystems **13**: 727-740
WATTS, A.C.; AMBROSIA, V.C.; HINKLEY, E.A. (2012): Unmanned aircraft systems in remote sensing and scientific research: classification and consideration of use. - Remote Sens **4**:1671-1692.
WHITED, D.; LORANG, M.S.; HARNER, M.; HAUER, R. KIMABLL; J.S.; STANFORD, J.A. (2007): Climate, Hydrology disturbance and succession: drivers of floodplain pattern. - Ecology **88**(4): 940–953.

Note: Full panorama views of the investigated river landscapes:
http://www.htw-dresden.de/fakultaet-geoinformation/labore/photogrammetrie-fernerkundung/projekte/mongolei.html

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